Secondary Student Mentorship and Research in Complex Networks: Process and Effects

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1 Background

Formal educational systems to date have not seriously considered how to engage students in understanding the explosion in big data and data-driven sciences that increasingly affect their lives, nor have they adequately prepared students for working and living in a data-driven society. Yet the twenty-first century STEM workforce needs specific skills in coping with and creating knowledge from large-scale streaming and multivariate data. The kinds of statistical, pattern-seeking, modeling, and probabilistic attributes inherent in so-called big data demand a thorough fluency in both exploratory and inductive skills to identify patterns and characterize their behavior across a wide range of differing environments and processes. Network science has emerged as a promising way to address these data-intensive, real-world problems.

Network science has its roots in graph theory, the mathematical/statistical study of connected systems as points (nodes or vertices) connected by lines (edges or links), which has been in use for over 250 years [1]. Graph theory was further developed for use in social network analysis (using graph theory to analyze the relationships in systems of social interaction), as interest in the applications of gestaltism beyond psychology emerged early in the twentieth century [2] and has been widely used since the 1950s [3]. Modern network science emerged toward the end of the twentieth century with the advent of powerful microcomputers, making it possible to apply statistical analysis and systems theory to large, complex datasets, seeking patterns and leveraging them for improved knowledge management and discovery

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[4]. Network science today is being used to understand everything from the human brain, to the origins of cancer, to the growth of cities, to our impact on the environment [5–7]. As the field of network science has grown and matured, so has its potential for improving understanding of complex natural and human-made phenomena in a number of domains. Its potential beneficiaries include not only researchers but also teachers, policy makers, businesspeople, and the general public as they cope with big data and complexity on a daily basis. As early as the 1970s, Jay Forrester identified the need for integrating complex connected and dynamical systems into K-12 education as an important life skill [8]. And there have been an increasing number of calls to include network theory in some form in K-12 education over the past 20 years [9–14].

However, over the last 25 years, there have been just a few disparate efforts to use network science, or graph theory, as a tool for instruction, include it in K-12 curriculum as a tool for students to use, or bring network science concepts and tools to a broad audience. Some examples include:

- The Mega Mathematics Project [15] developed by Los Alamos National Laboratory which includes a significant curriculum on graph theory but has not been widely adopted.
- The New York Hall of Science developed Connections: The Nature of Networks in 2004, the first public museum exhibition devoted exclusively to network science and emergence [16]. Although attended by millions of museum visitors, many of whom came away with a deeper understanding of the science and technology of connected systems, many visitors also struggled to develop a coherent understanding of the breadth and importance of network science and the exhibition closed in 2015 [17].
- The MapStats Curriculum developed by Rice University [12] attempted to introduce the statistical nature of "traveling salesman" type problems for middle school-aged students but was not adopted in schools;
- Connected: The Power of Six Degrees, a documentary on network science, aired briefly on the Science Channel in 2008; and
- The traveling exhibition Geometry Playground developed in 2009 by the Exploratorium includes activities on graph theory and networks, but even though visitor studies indicated that it improved attitudes and confidence toward geometry knowledge, it did not improve visitors' spatial reasoning and traveled to only a handful of museums [18].

These and other projects and programs intended to bring graph theory and network analysis to students and broader audiences have been slow to gain momentum, have not scaled well, are poorly coordinated, and are without a generalizable scope or structure.

The challenges revealed by these efforts indicated a need to rethink approaches to advanced learning of network science, making it more relevant to learners and providing opportunities to develop expertise in computational tools and network thinking. Network science can provide a pathway for students to learn about traditional topics across many disciplines, including social studies, science, computer science, and technology. Many of the problems explored through a network science approach are in the everyday experience of students and network conventions are part of our common vernacular, such as the network flow of air traffic, interconnectivity of coupled networks in political and social systems, and human networks as seen through technology activities such as Facebook, Twitter, and online social gaming. Computer platforms and tools for statistical analysis necessary for network analysis have become accessible to all and are increasingly intuitive and powerful to use. Yet exposure to these data-driven science skills has been unavailable to most students, and experiences working under researchers' or mentors' guidance are often most inaccessible to students underrepresented in STEM careers.

2 A New Approach: NetSci High

In 2010, a new effort called "NetSci High" was launched with a goal to bring network science into K-12 and informal learning settings. It began as the result of brainstorming at a network science meeting at the MIT Media Lab in which it was theorized that a pathway into accelerating student learning through deep engagement [19–21], and meaningful team research [22–26] could result in successful and enduring impact on heterogeneous groups of high school students. Goals for student learning were identified as follows:

1. Improve computational and statistical thinking and stimulate interest in computer programming and computational scientific methods by providing students and teachers with opportunities to create and analyze network models for real-world problems through a mentoring and training program and team research.
2. Increase students' potential for success in STEM in a technical career or college through applied problem solving across the curriculum with tested units of instruction that elucidate complex STEM topics and provide new applied approaches for critical thinking in STEM.
3. Prepare learners for twenty-first century science and engineering careers through the use of data-driven science literacy skills and motivate them to elucidate social and scientific problems relevant to the disciplines and their lives.
4. Help learners develop the following set of basic skills that are crucially needed to succeed in the twenty-first century data-driven work environment:
    - *Ability to synthesize*, seek, and analyze patterns in large-scale data systems.
    - *Improve facility with data visualization*, filtering, federating, and seeking patterns in complex data.
    - *Understand the changing role of models*, higher-order thinking, emphasizing exploratory skills to identify and characterize behavior of patterns in differing environments.
    - *Use network science and statistical approaches* to break down traditional silos to compare and contrast processes across domains.
    - *Build data fluency* to be able to identify, clean, parse, process, and apply appropriate analysis skills to large quantities of data.

- *Gain facility with data mining and manipulation* with increasingly semantic and statistical approaches, superseding logic models for searching and comparing data.
- *Understand the role of data sharing,* collaboration, interoperability of tools and data types, along with skills in using collaborative tools and methods to maximize data discovery.

Using a small amount of start-up support from NSF's Cyber-Enabled Discovery and Innovation fund, student/teacher teams were matched to network science research labs in the Northeast for year-long research projects, culminating in participation in the 2011 International School and Conference of Network Science (NetSci) at the Central European University in Budapest, Hungary. Because of the small amount of funding, only two of the seven student teams could be supported for travel, so the research projects were judged by a scientific committee made up of renowned network researchers, and the two winning project teams (from Thomas Edison and Flushing International High Schools in New York City) were sent to the conference to defend their work. All of the seven posters resulting from the research were presented at the poster sessions of the conference. The posters were also displayed at the 2011 Eighth International Conference on Complex Networks in Boston. The second year of NetSci High (2011–2012) offered scholarships to high school student teams. Two student teams participated from the Binghamton, NY, area, and the teams received a scholarship to attend the NetSci 2012 conference in Evanston, IL, and present their posters.

3 Network Science for the Next Generation

These earlier efforts resulted in positive outcomes for the participating students, enough so to encourage the organizers to scale up the project through funding from the National Science Foundation. The partnership expanded to include researchers from Boston University, and in 2012 the team was awarded a 3-year Innovative Technology Experiences for Students and Teachers (ITEST) grant from the National Science Foundation. The successful proposal – Collaborative Research: Network Science for the Next Generation – had a primary goal of providing a pathway for underserved high school students to engage in cutting-edge network science research, making accessible the power of network modeling and analysis. It was designed to provide opportunity for developing rigorous skills-based curricula and resources that utilize the rapidly growing science of complex networks, offering underserved students a context in which to learn computational and analytical skills for network-oriented data analysis. Importantly, it also gave the students a setting in which they could use these skills in original and independent research, leading to breakthroughs in solving large-scale, real-world problems and opening doors for future educational and career opportunities. The projects entailed intensive training and support of high school student teams and an academic year of research with cooperating university-based network science research labs; the labs' participation is facilitated by a graduate student who learns valuable mentorship skills as part of the experience. Because the network science field is relatively new, much of this research is novel, with practical implications.

Network Science for the Next Generation was designed as a regional educational outreach program. Over the course of the 3-year grant period (2012–2015), the project team formed close relationships with teachers and administrators from Title 1 high schools in both urban and rural areas in the Northeastern United States. ("Title 1" refers to a US Federal Department of Education program that provides financial assistance to schools with high numbers or high percentages of children from low-income families to help ensure that all children meet challenging state academic standards). By engaging Title 1 schools, the project adhered to its goal of providing opportunities to the students most likely to be left out of STEM career opportunities. Teachers recruited students for the project who were willing to make a commitment to a year-long project; however, in most cases, the students were not necessarily considered college-bound. The project team also recruited graduate students from research labs focused on network science applications, who would mentor the students throughout the school year.

These small teams–each made up of a teacher, 4 to 6 students, plus the grad student–were all required to attend an intensive 2-week summer workshop at which student teams, their teachers, and graduate student mentors are immersed in network science concepts; learn programming languages such as Python, NetLogo, and JavaScript; apply network analysis tools such as NetworkX and Gephi; attend hands-on workshops and talks from top network science researchers; and collaboratively brainstorm about research questions that will form the basis of the year's research projects. During the school year, the teams met regularly during and after school and submitted weekly progress reports and went on field visits to university labs, corporate headquarters, and science museums.

The culmination of each year was the presentation of the students' work at a major research conference; their posters were presented at the International School and Conference of Network Science in 2013, 2014, 2015, and 2016, and in several instances, the students themselves were present to defend their posters. In 2015 the organizers received a supplemental grant from NSF in order to bring all of the project students and teachers to the International Conference on Complex Networks (CompleNet). Each of these poster presentations experiences gave the students the opportunity to meet and talk with renowned researchers. In addition, one of the student projects–Spread of Academic Success in a High School Social Network–was published in PLOS One [27] (see Appendix for a complete list of student research projects).

4 Outcomes

The project bridged information technology practice and advances in network science research and provided career and technical education opportunities for young people underrepresented in data-driven STEM. The project team developed and implemented a rich, experiential, research-based program for 120 disadvantaged high school students, 30 science research graduate student mentors, and 20 high school STEM teacher mentors throughout New York State and Boston, Massachusetts. It provided participants with opportunities to engage with top network science researchers, to be exposed to university and research lab settings and potential career paths, to receive intensive skill-building and training, and most importantly, to make real contributions to the field through original research. For many of these students, this was a life-altering experience. The project also gave rise to several Network Science and Education ancillary efforts, described below, which are ongoing.

5 Evaluation

External evaluation of Network Science for the Next Generation (formative and summative) was conducted by Davis Square Research Associates [28, 29] (Figs. 1 and 2). Evaluation looked at a range of project goals such as proximal (e.g., increasing high school student competencies in computing and improving student attitudes toward computing) as well as highly distal (e.g., preparing students for twenty-first century science) learning outcomes, the emphasis on doing real-world research into relevant and ambiguous problems through technologically infused and highly collaborative projects, and cognitive goals such as analyzing, synthesizing, and visualizing quantitative data and understanding modeling, network statistics, etc. Evaluation also looked at outcomes of improving participant attitudes toward the study of networks, self-efficacy, and the strengthening intentions of continuing to pursue further involvement in college studies and careers. Guiding research questions included:

- What is the effect of participation on the students' understanding of networks and their skills at analyzing networks?

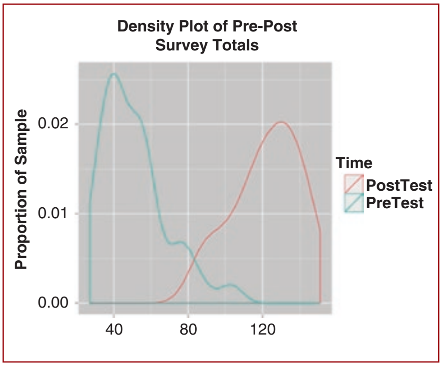

Fig. 1 Pre-Post density plots

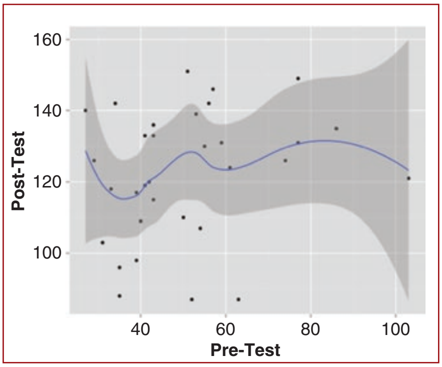

Fig. 2 Post-Test by Pre-Test

- How does participation affect the students' attitudes toward their own self-efficacy in computational approaches to networks and their commitments to continue to study networks in college and beyond?

Evaluation methods included gathering qualitative and quantitative data through focus groups, surveys, and SNA analyses. A significant challenge to the evaluation was the innovative nature of the project; since there was no or very little comparable activity, it was not possible to analyze any meaningful comparable groups.

Summative evaluation was intended to gather information on four pre-post constructs: knowledge of networks, intentions to continue studying networks, attitudes toward network science in general, and frequency of communications about networks [29]. Responding students reported large pre-post gains, especially in the areas of knowledge of network science and attitudes toward the study of networks. The effect sizes are very large, though these may be somewhat inflated due to a social desirability bias associable with the retrospective pretest design of the survey. None of the four constructs (knowledge, intentions, attitudes, communications) showed gain scores that were significantly clustered around the mean ($p < 0.05$, Kolmogorov-Smirnov [30]), indicating that some students gained more and others gained less, as could perhaps be inferred from the large standard deviations noted. The same observation held true for the aggregated pre-post gain scores.

The pretest scores were not predictive of the posttest scores. This is a good finding in that it suggests that the project worked comparably well with students no matter what their levels of preparation at the beginning of their participation. The following density plots show the very stark shift from the pretest to the posttest moments. The gray areas express the confidence interval.

Participating teachers were surveyed using open-ended questions about student network learning, student skills development, and a sustained student interest in careers. For each of the questions, teachers were asked to reflect on their own learning, their own network skills development, and the potential for sustained effects on their own practice. Responding teachers indicated that:

- They tended to cite the value of the more theoretical learning, with a special emphasis on the innovative qualities of the project.

- They were highly appreciative of students' new technical skills, with these skills clearly seen as having a distinct educational value.
- They saw the project as having an enormous educational value, with the network perspective likely to continue to influence the participating educators' approach to certain content. The previous finding that many students intended to continue to study networks, or to incorporate networks in their future studies, was confirmed by the responding teachers.

Overall, the external evaluation found that the project was consistently effective over the three years in reaching its most basic goals of improving students' understanding of networks, their self-efficacy with regard to the study of networks, the attribution of value regarding networks, and their intentions to continue to study networks. Key findings include:

- Participating students reported significant cognitive gains in their awareness of networks and their skills at using computers to analyze networks.
- Participating students reported significant gains in their attitudes toward the value of studying networks and their confidence in being successful at such studies.
- Both participating students and teachers reported they intended to continue to use network approaches.

Significant project outcomes revealed:

- Original student and teacher research projects are not only possible but form an essential incentive and commitment for participants to remain engaged in and to bring projects to completion.
- It is possible to train a broad spectrum of students and teachers in enough computer programming (e.g., Python or R) to use sophisticated network analysis tools within programing environments.
- A supportive community and consistent mentorship are essential to success.
- Teachers can assume an active leadership role in mentoring students who are engaged in network science research provided adequate supports are in place.
- Students and teachers are remarkably innovative in terms of how they develop and pursue project-based learning approaches in network science.

Students reported high levels of engagement in projects that used real-world, active learning in highly collaborative teams. Overcoming the social barriers to collaboration and the technical and logistical challenges all proved to be of great worth to the participating students. The role of the faculty and graduate student mentors was also of great value, providing prompt and clear feedback as the projects developed. This combination of meaningful challenge with attentive and thoughtful guidance is of the greatest educational value. It is extremely effective for students in incentivizing and achieving success in mastering and applying data-driven STEM skills to real problem solving and is an empowering and engaging pathway into data and computational literacy and computer programming skills.

6 Conclusions

Over the past 8 years of NetSci High, it has become evident that a successful program of learning about the science of complex networks is achievable for heterogeneous groups of high school students from underrepresented groups, provided there is the right support "ecosystem." This ecosystem includes:

- Deep engagement in learning about network science and applying network science tools and techniques in a variety of ways, including training in enough computer programming (e.g., Python or R) to use sophisticated network analysis tools
- Highly collaborative student-teacher-mentor teams that persist throughout the life of the project
- Opportunity for students to innovate in terms of how they develop and pursue project-based learning approaches in network science, make mistakes, and explore a variety of avenues for creativity
- Original team research projects that form an essential incentive and commitment for participants to remain engaged and to bring projects to completion
- A supportive community and consistent mentorship, including an active leadership role for teachers who are allowed enough time to mentor students and are able to maintain contact with researchers

It became immediately apparent during the first year of Network Science for the Next Generation that participating teachers were most effective if they had, at a minimum, the same level of training as their students before being called upon to mentor students: they wanted to be active mentors, rather than co-learners with their students. As the project progressed, interactions with teachers became deeper and more meaningful, and teachers took on new roles, pursued their own interests, and took ownership of network science approaches. Original student and teacher research projects are not only possible but form an essential incentive and commitment for participants to remain engaged in and to bring projects to completion. A path to scalability began to emerge.

NetSci High has made significant educational impacts on regional high school students and teachers and is also prompting strong social commitments from the network science community as a whole [31, 32]. It aims to address the challenge of transforming the way we educate our citizens to keep pace with not only the amount of data we collect but to appreciate how network science identifies, clarifies, and solves complex twenty-first century challenges in the environment, medicine, agriculture urbanization, social justice, and human well-being. NetSci High provides a pathway to integrate science research and programming skills for high school students who would not otherwise have these opportunities. Additionally, it encourages high school teacher mentors to broaden their STEM understanding and informs their current teaching in terms of content and practice. Success in NetSci High elicits students to persist in interest in STEM and computational fields and attain ambitious academic goals.

7 Other NetSci Community Efforts

The work described above has resulted in the growth of an active Network Science in Education global community, also known as NetSciEd. Several ongoing streams of collaborative work have resulted.

7.1 NetSciEd Satellites

NetSci High organizers are dedicated to supporting the growth of network science education efforts. A key venue for support takes place at the annual International School and Conference on Network Science (NetSci), where the Network Science and Education (NetSciEd) satellite symposium has taken place since 2012 [33]. NetSciEd provides an opportunity for the growing community of network scientists interested in education to come together to exchange ideas, talk about their projects and programs, demonstrate and get feedback on new tools, and discuss curriculum models.

7.2 Network Literacy

Attaining a basic understanding of networks has become a necessary form of literacy for all people living in today's society and for young people in particular. At the 2014 International School and Conference on Network Science, a year-long process was initiated to develop an educational resource that concisely summarizes essential concepts about networks that can be used by anyone of school age and older. The process involved several brainstorming sessions on one key question: "What should every person living in the twenty-first century know about networks by the time he/she finishes secondary education?" These brainstorming sessions reached diverse participants, which included professional researchers in network science, educators, and high school students. The generated ideas were connected by the students to construct a concept network. We examined community structure in the concept network to group ideas into a set of important concepts, which, through extensive discussion, we further refined into seven essential concepts [34]. The students played a major role in this developmental process by providing insights and perspectives that were often unrecognized by researchers and educators. The final result, "Network Literacy: Essential Concepts and Core Ideas," is now available as a booklet and has been translated into 20 languages [35]. (See Appendix for complete text.)

7.3 Learning Settings

Among the goals of NetSci High was to have teachers integrate network science into instruction. Concurrent with the NetSci High student training and research project is a multiphase, multiyear approach to professional development with formal and informal educators, including efforts to facilitate the development of practices and resources with educators and promote network thinking among K-12 students, teachers, and administrators through developing curriculum materials, lesson plans, and practical learning resources for K-12 classrooms across all domains of knowledge; providing rigorous professional development opportunities for both formal (school) and informal (cultural institutions, camps, after-school, and other community-based programs) educators; increasing the awareness of the demand for network science education among researchers; and developing a path for mapping *Network Literacy Essential Concepts and Core Ideas* to learning standards such as Next Generation Science Standards (NGSS) [36]. And, most recently, one of the NetSci High participating school districts includes a class on Network Literacy in its official after-school course catalogue, taught by a participating NetSci High veteran educator.

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Appendices

NetSci High Student Research Projects 2010–2015

2010–2011

- A Comparative Study on the Social Networks of Fictional Characters
- Academic Achievement and Personal Satisfaction in High School Social Networks
- Does Facebook Friendship Reflect Real Friendship?
- Inter-Species Protein-Protein Interaction Network Reveals Protein Interfaces for Conserved Function
- The Hierarchy of Endothelial Cell Phenotypes
- Preaching To The Choir? Using Social Networks to Measure the Success of a Message
- Identification of mRNA Target Sites for siRNA Mediated VAMP Protein Knockdown in *Rattus norvegicus*

2011–2012

- A Possible Spread of Academic Success in a High School Social Network: A Two-Year Study
- Research on Social Network Analysis from a Younger Generation

2012–2013

- Interactive Simulations and Games for Teaching about Networks
- Mapping Protein Networks in Three Dimensions
- Main and North Campus: Are We Really Connected?
- High School Communication: Electronic or Face-to-Face?
- An Analysis of the Networks of Product Creation and Trading in the Virtual Economy of Team Fortress 2

2013–2014

- A Network Analysis of Foreign Aid Based on Bias of Political Ideologies
- Comparing Two Human Disease Networks: Gene-Based and System-Based Perspectives
- How Does One Become Successful on Reddit.com?
- Influence at the 1787 Constitutional Convention
- Quantifying Similarity of Benign and Oncogenic Viral Proteins Using Amino Acid Sequence
- Quantification of Character and Plot in Contemporary Fiction
- RedNet: A Different Perspective of Reddit
- Tracking Tweets for the Superbowl

2014–2015

- Network Analysis of Microgravity-Influenced Genes in *Salmonella enterica serovar typhimurium*
- Connecting Radon Levels to Cancer rates in California Counties: A Network Approach
- National Football League Network
- Drug combinations and adverse side effects
- Comparing post-secondary institutions across the United States
- Relationships Between Musculoskeletal System and High School Sports Injuries
- Similarities Found in Neurological Disorders Based on Mutated Genes and Drug Molecules
- The Relationships of International Superpowers
- Protein Association and Nucleotide Similarities Among Human Alpha-Papillomaviruses

Network Literacy: Essential Concepts and Core Ideas

1. Networks are everywhere.
    - The concept of networks is a broad, general idea about how things are connected and working together. Networks are present in every aspect of life.
    - There are networks that form the technical infrastructure of our society (e.g., communication systems, the Internet, the electric grid, the water supply).
    - There are networks of people, e.g., families and friends, email/text exchanges, Facebook/Twitter/Instagram, and professional groups.
    - There are economic networks, e.g., financial transactions, corporate partnerships, and international trades.
    - There are biological/ecological networks, e.g., food webs, gene/protein interactions, neural networks, and spread of diseases.
    - There are cultural networks, e.g., language, literature, art, history, and religion.
    - Networks can exist at various spatial and/or temporal scales.
2. Networks describe how things connect and interact.
    - There is a subfield of mathematics that applies to networks. It is called graph theory. A graph in mathematics means a network.
    - Connections are called links, edges, and ties. Things that are connected are called nodes, vertices, and actors.
    - Connections can be undirected (symmetric) or directed (asymmetric).
    - The number of connections a node has is called a degree of that node.
    - In some networks, you can find a small number of nodes that have much larger degrees than others. They are called hubs.
    - A sequence of links that leads you from one node, through other nodes, to another node is called a path.
    - In some networks, you can find a group of nodes that are well connected to each other. They are often called clusters, cliques, and communities.
3. Networks help reveal patterns.
    - You can represent something as a network by describing what its parts are and how they are connected to each other. Such network representation is a very powerful way to study its properties.
    - Some of the properties in a network that you can study are:
        - How the degrees are distributed across nodes.
        - Which parts or connections are the most important ones.
        - Strengths and/or weaknesses of the network.
        - If there is any substructure or hierarchy.
        - How many hops, on average, are needed to move from one node to another within the network.
        - Using these findings, you may be able to make predictions.

4. Visualizations can provide an understanding of networks.
   - Networks can be visualized in a number of different ways.
   - You can draw a diagram of a network by connecting nodes with links.
   - There are a variety of tools available for visualizing networks.
   - Visualization of a network often helps to understand it and communicate the ideas to people in an intuitive, nontechnical way.
   - Creative information design plays a very important role in making an effective visualization.
   - It is important to be careful when interpreting and evaluating visualizations, because they may not tell the whole story about the networks.
5. Today's computer technology allows us to study real-world networks.
   - Computer technology has dramatically enhanced our ability to study networks, especially large complex ones.
   - There are many free software tools available for network visualization and analysis.
   - Using personal computers, everyone can easily model, visualize, and analyze networks, not just scientists.
   - Through the Internet, everyone has access to many interesting network data.
   - Computers allow us to simulate hypothetical or virtual networks, as well as real ones.
   - Learning basic computer literacy skills opens the door to infinite possibilities, e.g., file/folder operation, data entry, manipulation and modeling, information sharing and collaboration, and computer programming.
6. Networks help us compare a wide variety of systems.
   - Various kinds of systems, once represented as networks, can be compared to see how similar or different they are.
   - Certain network properties commonly appear in many seemingly unrelated systems. This implies that there may be some general network principles across disciplines.
   - Other network properties are quite different from systems to systems. These properties can help classify networks in different families and understand them differently.
   - Science has traditionally been conducted in separate disciplines. Networks can help go beyond disciplinary boundaries toward a more cross- or interdisciplinary understanding of the world.
   - Networks can help transfer knowledge from one discipline to another to make a breakthrough.
7. Network structures can influence their dynamics and vice versa.
   - Network structure means how parts are connected in a network.
   - Network dynamics means how things change over time in a network.

- Network structures can influence their dynamics. Examples include the spread of diseases, behaviors or memes in a social network, and traffic patterns on the road network in a city.
- Network dynamics can influence their structures. Examples include the creation of new following links in social media and construction of new roads to address traffic jams.
- Network structures and dynamics often influence each other simultaneously.

Outreach Events

- NetSci High has facilitated sending a group of high school students and teachers from New York City to NetSci 2011 in Budapest, Hungary; a group from Endwell and Vestal, NY to NetSci 2012 in Evanston, IL; and a group from Vestal, NY to NetSci 2014 in Berkeley, CA. In all of these travels, the high school student teams presented their work at poster sessions. High school student research has also been published in peer-reviewed journals such as PLOS One (Blansky et al. 2013).
- Students and teachers from Newburgh Free Academy and Vestal High School presented posters at the IEEE ISEC conference at Princeton University in 2015 and 2016. NetSci High participating students and teachers have presented at the West Point Cadet Seminar on Network Science each year of NetSci High.
- In 2016 NetSci High students and teachers participated in the US Science and Engineering Festival in Washington, D.C., presenting several hands-on activities related to the Network Literacy Essential Concepts.

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